Measurements of branching fractions for inclusive $\overline{K}^0/K^0$ and $K^*(892)^\mp$ decays of neutral and charged D mesons

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Using the data sample of about 33 pb^{-1} collected at and around 3.773 GeV with the BES-II detector at the BEPC collider, we have studied inclusive $\overline{K}^0/K^0$ and $K^*(892)^\mp$ decays of D^0 and D^+ mesons. The branching fractions for the inclusive $\overline{K}^0/K^0$ and $K^*(892)^-$ decays are measured to be $BF(D^0 \to \overline{K}^0/K^0X) = (47.6 \pm 4.8 \pm 3.0)\%$, $BF(D^+ \to \overline{K}^0/K^0X) = (60.5 \pm 5.5 \pm 3.3)\%$, $BF(D^0 \to K^{*-}X) = (15.3 \pm 8.3 \pm 1.9)\%$ and $BF(D^+ \to K^{*-}X) = (5.7 \pm 5.2 \pm 0.7)\%$. The upper limits of the branching fractions for the inclusive $K^*(892)^+$ decays are set to be $BF(D^0 \to K^{*+}X) < 3.6\%$ and $BF(D^+ \to K^{*+}X) < 20.3\%$ at 90% confidence level.

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I. INTRODUCTION

Measurements of the branching fractions for inclusive $\overline{K}^0/K^0$ and $K^{*\mp}$ decays of D mesons are important in understanding of the D decay mechanisms. Comparing the measured inclusive branching fraction with the sum of those for the exclusive decays [1] provides some information about the decay modes which have not been observed yet. In addition, measurements of the branching fractions for the inclusive K^{*-} and K^{*+} decays of D mesons can also help us to study the relative strength of the Cabibbo-favored and Cabibbo-suppressed decays. Up to now, these branching fractions have not been measured yet.

This Letter reports measurements of the branching fractions for the inclusive decays $D \to \overline{K}^0/K^0X$ (X=any particles) and $D \to K^{*\mp}X$. The branching fractions are obtained based on analyses of the data sample of integrated luminosity of 33 pb^{-1} collected with the BES-II detector at and around 3.773 GeV. Throughout the Letter, charge conjugation is implied.

II. BES-II DETECTOR

The BES-II is a conventional cylindrical magnetic detector [2] operated at the Beijing Electron-Positron Collider (BEPC). A 12-layer Vertex Chamber (VC) surrounding the beryllium beam pipe provides input to the event trigger, as well as coordinate information. A forty-layer main drift chamber (MDC) located just outside the VC yields precise measurements of charged particle trajectories with a solid angle coverage of 85% of 4π; it also provides ionization energy loss (dE/dx) measurements which are used for particle identification. Momentum resolution of $1.7\%\sqrt{1+p^2}$ (p in GeV/c) and dE/dx resolution of 8.5% for Bhabha scattering electrons are obtained for the data taken at $\sqrt{s}$ = 3.773 GeV. An array of 48 scintillation counters surrounding the MDC measures the time of flight (TOF) of charged particles with a resolution of about 180 ps for electrons. Outside the TOF, a 12 radiation length, lead-gas barrel shower counter (BSC), operating in limited streamer mode, measures the energies of electrons and photons over 80% of the total solid angle with an energy resolution of $\sigma_E/E = 0.22/\sqrt{E}$ (E in GeV) and spatial resolutions of σ_ϕ = 7.9 mrad and σ_Z = 2.3 cm for electrons. A solenoidal magnet outside the BSC provides a 0.4 T magnetic field in the central tracking region of the detector. Three double-layer muon counters instrument the magnet flux return and serve to identify muons with momentum greater than 500 MeV/c. They cover 68% of the total solid angle.

III. DATA ANALYSIS

Around the center-of-mass energy of 3.773 GeV, $\psi(3770)$ is produced in the annihilation of e^+e^-. It decays to $D\bar{D}$ pairs ($D^0\bar{D}^0$ or D^+D^-) with a large branching fraction of about (85±6%) [3]. These provide us a unique method to directly measure the branching fractions for D meson decays. In the analyses we first reconstruct a $\bar{D}$ meson of the $D\bar{D}$ pair (this is called a singly tagged $\bar{D}$), then select the inclusive decays $D \to \overline{K}^0/K^0X$ or $D \to K^{*\mp}X$ on the recoil side of the singly tagged $\bar{D}$, and measure the absolute branching fractions for these decays.

A. Events selection

To select the candidate events for the decays, it is first required that at least two charged tracks be well reconstructed in the MDC with good helix fits. In order to ensure the well-measured 3-momentum vectors and the reliability of the charged-particle identification, the polar angle θ of each charged track must satisfy $|\cos\theta| < 0.85$. It is then required that each charged track, except for those from K^0_S, originate from the interaction region defined by $\sqrt{V_x^2+V_y^2} < 2.0$ cm and $|V_z| < 20.0$ cm, where V_x, V_y and V_z are the closest approach of the charged track in the x, y and z directions.

Pions and kaons are identified using the dE/dx and TOF measurements, with which the combined confidence levels (CL_π or CL_K) for a pion or kaon hypotheses are calculated. A pion candidate is required to have $CL_\pi > 0.001$ and a kaon candidate is required to satisfy $CL_K > CL_\pi$.

Neutral pions are reconstructed through the decay $\pi^0 \to \gamma\gamma$. For the γ from π^0 decay, the energy deposited in the BSC is required to be greater than 70 MeV; the electromagnetic shower is required to start in the first 5 readout layers; and the angle between the γ and the nearest charged track is required to be greater than 22° [4, 5].

B. Singly tagged $\bar{D}^0$ and D^- samples

The singly tagged $\bar{D}^0$ and D^- samples used in the analyses have been selected in the previous works [4, 5], where the $\bar{D}^0$ mesons are reconstructed in four hadronic decay modes $K^+\pi^-$, $K^+\pi^-\pi^-\pi^+$, $K^0\pi^+\pi^-$ and $K^+\pi^-\pi^0$ ($Kn\pi$, n= 1, 2, 3), and the D^- mesons are reconstructed in nine hadronic decay modes $K^+\pi^-\pi^-$, $K^0\pi^-$, K^0K^-, $K^+K^-\pi^-$, $K^0\pi^-\pi^-\pi^+$, $K^0\pi^-\pi^0$, $K^+\pi^-\pi^-\pi^0$, $K^+\pi^+\pi^-\pi^-\pi^-$ and $\pi^+\pi^-\pi^-$ ($mKn\pi$, m=0, 1, 2; n=0, 1, 2, 3, 4). These give the total numbers $7584 \pm 198(\text{stat.}) \pm 341(\text{sys.})$ singly tagged $\bar{D}^0$ mesons [4] and $5321 \pm 149(\text{stat.}) \pm 160(\text{sys.})$ singly tagged D^- mesons [5].

C. Candidates for $D \to \overline{K}^0/K^0X$ and $D \to K^{*-}(K^{*+})X$

Candidates for the inclusive decays $D \to \overline{K}^0/K^0X$ and $D \to K^{*-}(K^{*+})X$ are selected from the survival tracks on the recoil side of the singly tagged $\bar{D}$. Neutral kaons are reconstructed through the decay $K_S^0 \to \pi^+\pi^-$. We require that $\pi^+\pi^-$ must originate from a secondary vertex which is displaced from the event primary vertex by 7 mm at least. $K^{*-}(K^{*+})$ mesons are reconstructed through the decay $K^{*-}(K^{*+}) \to K_S^0\pi^-(K_S^0\pi^+)$.

In each invariant masses spectrum for the $mKn\pi$ combinations, the region within a $\pm 3\sigma_{M_{\bar{D}_i}}$ window around the fitted $\bar{D}$ mass $M_{\bar{D}_i}$ is defined as the singly tagged $\bar{D}$ signal region, where $\sigma_{M_{\bar{D}_i}}$ is the standard deviation of the mass spectrum for the ith tag mode. The region outside a $\pm 4\sigma_{M_{\bar{D}_i}}$ window around the fitted $\bar{D}$ mass is taken as the $\bar{D}$ sideband region. In order to estimate the number of background events in the $\bar{D}$ signal regions, the number of the $\bar{D}$ sideband events is normalized by the ratio of the area of the fitted background in the $\bar{D}$ signal region to that of the $\bar{D}$ sideband.

Figures 1 and 2 show the distributions of the $\pi^+\pi^-$ invariant masses for the events observed on the recoil side of the $\bar{D}^0$ and D^- tags for studying $D \to \overline{K}^0/K^0X$. In each figure, (a) is the mass spectrum for the events with the $mKn\pi$ invariant masses in the $\bar{D}$ signal regions, and (b) is the normalized mass spectrum for the $\bar{D}$ sideband events. Fitting each mass spectrum with a Gaussian function for K_S^0 signal and a polynomial to describe the background shape, the numbers of K_S^0 mesons are obtained. These numbers are summarized in Table I, where N and N_b are the numbers of K_S^0 mesons observed from the events with the $mKn\pi$ invariant masses in the $\bar{D}$ signal and $\bar{D}$ sideband regions, respectively. Subtracting N_b from N, we obtain the number n of the signal events for $D \to \overline{K}^0/K^0X$.

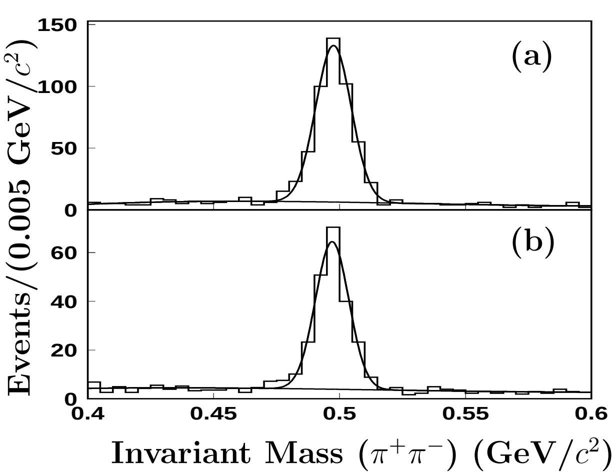

FIG. 1: The distributions of the $\pi^+\pi^-$ invariant masses for the events observed on the recoil side of the $\bar{D}^0$ tags for studying $D^0 \to \overline{K}^0/K^0X$; (a) is the mass spectrum for the events with the $Kn\pi$ invariant masses in the $\bar{D}^0$ signal region; (b) is the normalized mass spectrum for the $\bar{D}^0$ sideband events.

Figures 3, 4, 5 and 6 show the distributions of invariant masses for the $K_S^0\pi^-$ or $K_S^0\pi^+$ combinations observed on the recoil side of $\bar{D}^0$ or D^- tags respectively for studying the decays $D \to K^{*-}(K^{*+})X$. In each figure, (a) is the mass spectrum for the events in which the $mKn\pi$ invariant masses are in the $\bar{D}$ signal regions, and (b) is the normalized mass spectrum for the $\bar{D}$ sideband events. The histograms are for the events with the $\pi^+\pi^-$ invariant masses in the K_S^0 signal region (within a $\pm 3\sigma_{M_{K_S^0}}$ window around the fitted K_S^0 mass), and the shadows are the normalized background estimated by K_S^0 sideband (outside a $\pm 4\sigma_{M_{K_S^0}}$ window around the fitted K_S^0 mass). Fitting each mass spectrum with a Gaussian function for $K^{*-}(K^{*+})$ signal and a polynomial to describe the background shape, we obtain the numbers of $K^{*-}(K^{*+})$ mesons. In the fit, the mass and width of $K^{*-}(K^{*+})$ are fixed to 0.8917 GeV/c^2 and 0.0508 GeV/c^2 quoted from PDG [1], and the detector resolution is set to be 0.0116 GeV/c^2 determined by Monte Carlo simulation. Table I also summarizes the numbers of N, N_b and n for the study of $D \to K^{*-}(K^{*+})X$.

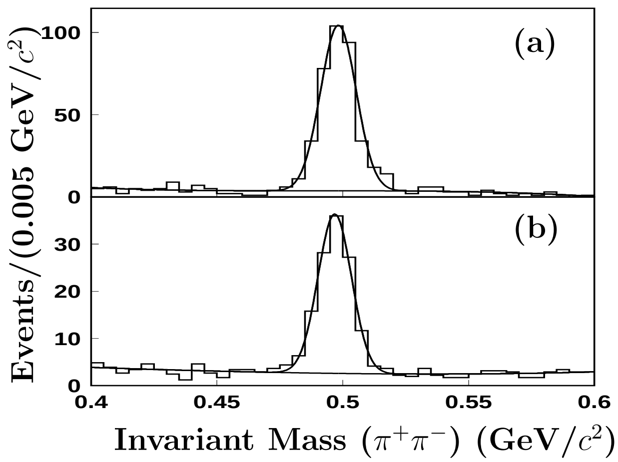

FIG. 2: The distributions of the $\pi^+\pi^-$ invariant masses for the events observed on the recoil side of the D^- tags for studying $D^+ \to \overline{K}^0/K^0X$; (a) is the mass spectrum for the events with the $mKn\pi$ invariant masses in the D^- signal regions; (b) is the normalized mass spectrum for the D^- sideband events.

IV. RESULTS

A. Monte Carlo efficiency

The detection efficiencies for the inclusive $\overline{K}^0/K^0$ and $K^{*-}(K^{*+})$ decays of D mesons are estimated by Monte Carlo simulation. The Monte Carlo events are generated as $e^+e^- \to D\bar{D}$, where $\bar{D}$ decays into the singly tagged $\bar{D}$ modes and D decays into $\overline{K}^0/K^0X$ or $K^{*-}(K^{*+})X$. The particle trajectories are simulated with the GEANT3

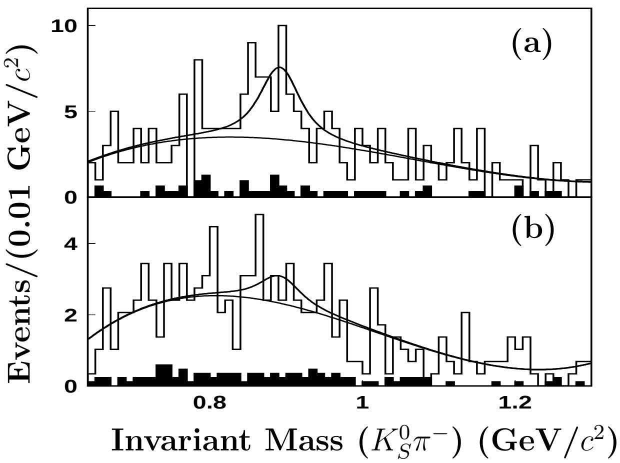

FIG. 3: The distributions of the $K^0_S\pi^-$ invariant masses for the events observed on the recoil side of the $\bar{D}^0$ tags for studying $D^0 \to K^{*-}X$; (a) is the mass spectrum for the events with the $Kn\pi$ invariant masses in the $\bar{D}^0$ signal regions; (b) is the normalized mass spectrum for the $\bar{D}^0$ sideband events; the shadows are the normalized background estimated by K^0_S sideband.

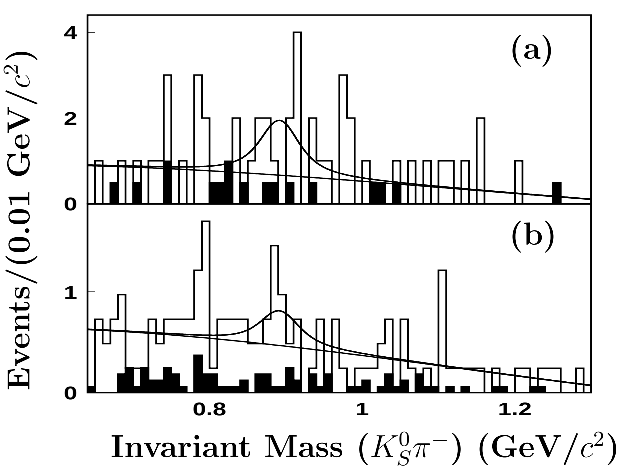

FIG. 4: The distributions of the $K^0_S\pi^-$ invariant masses for the events observed on the recoil side of the D^- tags for studying $D^+ \to K^{*-}X$; (a) is the mass spectrum for the events with the $mKn\pi$ invariant masses in the D^- signal regions; (b) is the normalized mass spectrum for the D^- sideband events; the shadows are the normalized background estimated by K^0_S sideband.

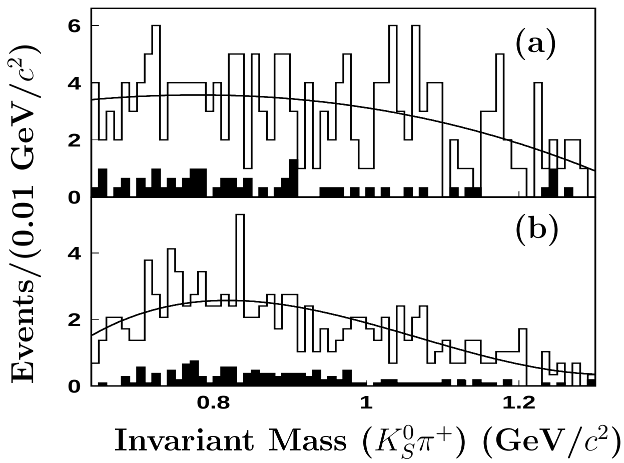

FIG. 5: The distributions of invariant masses for the $K^0_S\pi^+$ combinations observed on the recoil side of the $\bar{D}^0$ tags for studying $D^0 \to K^{*+}X$; (a) is the mass spectrum for the events with the $Kn\pi$ invariant masses in the $\bar{D}^0$ signal regions; (b) is the normalized mass spectrum for the $\bar{D}^0$ sideband events; the shadows are the normalized background estimated by K^0_S sideband.

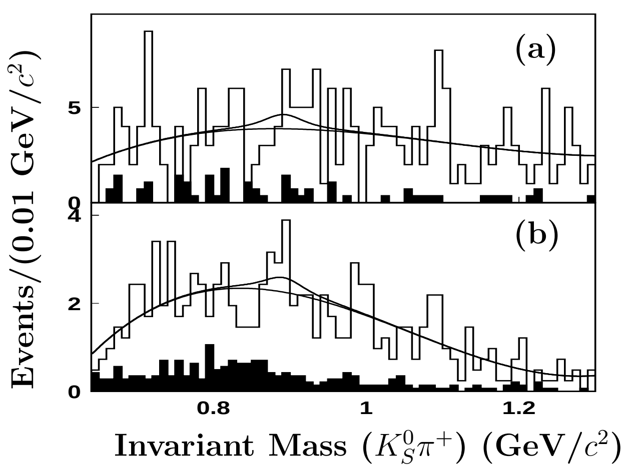

FIG. 6: The distributions of the invariant masses of $K^0_S\pi^+$ combinations observed on the recoil side of the D^- tags for studying $D^+ \to K^{*+}X$; (a) is the mass spectrum for the events with the $mKn\pi$ invariant masses in the D^- signal regions; (b) is the normalized mass spectrum for the D^- sideband events; the shadows are the normalized background estimated by K^0_S sideband.

based Monte Carlo simulation package of the BES-II detector [6]. Weighting the efficiencies by the branching fractions of D decays quoted from PDG [1] and the numbers of the singly tagged $\bar{D}$ mesons, we obtain the averaged efficiencies to be $(6.94 \pm 0.06)\%$ for $D^0 \to \overline{K}^0/K^0X$, $(7.57 \pm 0.06)\%$ for $D^+ \to \overline{K}^0/K^0X$, $(2.56 \pm 0.04)\%$ for $D^0 \to K^{*-}(K^{*+})X$ and $(2.36 \pm 0.06)\%$ for $D^+ \to K^{*-}(K^{*+})X$.

TABLE I: Summary of the numbers of K_S^0 and $K^{*\mp}$ mesons observed on the recoil side of the $\bar{D}$ tags, where N and N_b are the numbers of K_S^0 or $K^{*\mp}$ mesons observed from the events with the $mKn\pi$ invariant masses in the $\bar{D}$ signal regions and $\bar{D}$ sideband regions, respectively, and n is the number of the signal events of the inclusive decays.

Decay mode	N	N_b	n
$D^0 \to \overline{K}^0/K^0X$	443.7±23.6	193.4±9.4	250.3±25.4
$D^+ \to \overline{K}^0/K^0X$	352.4±21.1	108.7±6.1	243.7±22.0
$D^0 \to K^{*-}X$	33.7±13.8	6.1±5.7	27.6±14.9
$D^+ \to K^{*-}X$	10.0±6.2	2.8±2.0	7.2±6.5
$D^0 \to K^{*+}X$	-0.7±2.8	-0.1±2.1	-0.6±3.5
$D^+ \to K^{*+}X$	5.2±11.9	2.5±4.2	2.7±12.6

B. Branching fractions

The branching fractions for the inclusive decays $D \to \overline{K}^0/K^0X$ and $D \to K^{*-}X$ are determined by dividing the numbers of the signal events by the numbers of the singly tagged $\bar{D}$ mesons and the detection efficiencies. The branching fractions for the inclusive decays are

$$BF(D^0 \to \overline{K}^0/K^0X) = (47.6 \pm 4.8 \pm 3.0)\%, \quad (1)$$

$$BF(D^+ \to \overline{K}^0/K^0X) = (60.5 \pm 5.5 \pm 3.3)\%, \quad (2)$$

$$BF(D^0 \to K^{*-}X) = (15.3 \pm 8.3 \pm 1.9)\% \quad (3)$$

and

$$BF(D^+ \to K^{*-}X) = (5.7 \pm 5.2 \pm 0.7)\%, \quad (4)$$

where the first error is statistical and the second systematic.

The upper limits of the branching fractions for the inclusive decays $D^0 \to K^{*+}X$ and $D^+ \to K^{*+}X$, which include the systematic errors, are set to be

$$BF(D^0 \to K^{*+}X) < 3.6\% \quad (5)$$

and

$$BF(D^+ \to K^{*+}X) < 20.3\% \quad (6)$$

at 90% confidence level.

In the measurement of the branching fractions for $D^0 \to K^{*-}X$ and $D^0 \to K^{*+}X$, we use three singly tagged D^0 modes ($K^+\pi^-$, $K^+\pi^-\pi^-\pi^+$ and $K^+\pi^-\pi^0$). These give us $7033 \pm 193(\mathrm{stat.}) \pm 316(\mathrm{sys.})$ singly tagged $\bar{D}^0$ mesons. In the measured branching fractions, the systematic error arises from the uncertainties in particle identification ($\sim$ 0.5% per track), in tracking ($\sim$ 2.0% per track), in the number of the singly tagged $\bar{D}$ mesons ($\sim$ 4.5% for $\bar{D}^0$ and $\sim$ 3.0% for D^-) [4, 5], in K_S^0 selection ($\sim$ 1.1%) [5], in background parameterization (1.3% $\sim$ 9.3%) and in Monte Carlo statistics (0.8% $\sim$ 2.5%). Adding these uncertainties in quadrature yields the total systematic error to be 6.4% for $D^0 \to \overline{K}^0/K^0X$, 5.4% for $D^+ \to \overline{K}^0/K^0X$, 12.2% for $D^0 \to K^{*-}(K^{*+})X$ and 11.9% for $D^+ \to K^{*-}(K^{*+})X$. Table II presents the comparison of the measured branching fractions with those measured by MARKIII [7] and those given by PDG [1].

TABLE II: Comparison of the measured branching fractions for the inclusive decays with those measured by MARKIII [7] and those given by PDG [1].

$BF(\%)$	BES-II	MARKIII	PDG
$D^0 \to \overline{K}^0/K^0X$	47.6±4.8±3.0	45.5±5.0±3.2	42±5
$D^+ \to \overline{K}^0/K^0X$	60.5±5.5±3.3	61.2±6.5±4.3	61±8
$D^0 \to K^{*-}X$	15.3±8.3±1.9	-	-
$D^+ \to K^{*-}X$	$5.7 \pm 5.2 \pm 0.7$	-	-
$D^0 \to K^{*+}X$	<3.6	-	-
$D^+ \to K^{*+}X$	<20.3	-	-

V. SUMMARY

In conclusion, using the data sample of about 33 pb^{-1} collected at and around 3.773 GeV with the BES-II detector at the BEPC collider, we have studied the inclusive $\overline{K}^0/K^0$ and $K^{*\mp}$ decays of D mesons. The branching fractions for the inclusive $\overline{K}^0/K^0$ decays are determined to be $BF(D^0 \to \overline{K}^0/K^0X) = (47.6 \pm 4.8 \pm 3.0)\%$ and $BF(D^+ \to \overline{K}^0/K^0X) = (60.5 \pm 5.5 \pm 3.3)\%$, which are in good agreement with those measured by MARKIII and those given by PDG. The branching fractions for the inclusive K^{*-} decays are determined to be $BF(D^0 \to K^{*-}X) = (15.3 \pm 8.3 \pm 1.9)\%$ and $BF(D^+ \to K^{*-}X) = (5.7 \pm 5.2 \pm 0.7)\%$. These are measured for the first time. The upper limits of the branching fractions for the inclusive K^{*+} decays are set to be $BF(D^0 \to K^{*+}X) < 3.6\%$ and $BF(D^+ \to K^{*+}X) < 20.3\%$ at 90% confidence level.

VI. ACKNOWLEDGMENTS

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